THE VALIDATION OF SCIAMACHY PRODUCTS BY GROUND-BASED MILLIMETRE-WAVE OBSERVATIONS

Michael Hoock, Kai Lindner, Ingo Wohltmann, Klaus F. Künzi
Institute of Environmental Physics (IUP)
University of Bremen, PO Box 330 440, D-28203 Bremen, Germany.
Email: mh@ramweb.physik.uni-bremen.de

Hermann Berg, Gerd Hochschild, Gerhard Kopp
Institute of Meteorology and Climate Research (IMK)
Forschungszentrum Karlsruhe, PO Box 3640,, D-76021 Karlsruhe, Germany.

ABSTRACT

SCIAMACHY measurements of ozone (O_3), nitrous oxide (N_2O), water vapour (H_2O) and optional chlorine monoxide (ClO) shall be validated by profiles and columns derived from mm-wave radiometry at stations operating at high-, mid- and tropical latitudes (Fig.1).

The University of Bremen and the Forschungszentrum Karlsruhe will carry out the project jointly with support by the Universidad de los Andes in Mérida, Venezuela, for the tropical station. The University of Bremen is responsible for the maintenance and the operation of the high and mid-latitude stations. The high latitude station in Ny-Ålesund, Spitsbergen is equipped with three radiometers to measure ozone, water vapour and chlorine monoxide. At the mid-latitude station in Bremen, Germany, an ozone radiometer, also providing total columns of water vapour is operational since end of 2000 and presently in the validation phase. This latter instrument will be operated continuously during the time SCIAMACHY is in orbit. The Forschungszentrum Karlsruhe will install a well tested radiometer permitting to measure ozone, chlorine monoxide, nitrous oxide, nitric acid (HNO_3), and tropospheric water vapour columns at the high altitude equatorial site in Mérida, Venezuela. The University of Bremen will contribute a second frontend to observe stratospheric water vapour.

INTRODUCTION

The accuracy of satellite sensors depends on regular comparison to well calibrated and stable ground-based instruments. Such reference sensors are provided e.g. by the “Network for the Detection of Stratospheric Change” (NDSC). Millimetre-wave radiometers are very suitable for this purpose and have successfully been used in atmospheric research since the 1960s. Millimetre-wave radiometry enables nearly continiuous monitoring due to its independence from solar illumination and clear sky conditions. This results in a high number of matches between the ground-based observations and the satellite overpasses. Furthermore such sensors have excellent long term stability, and can be absolutely calibrated using black body radiators. Sensor technology has greatly improved over the past decade resulting in lower instrumental noise and better performance at higher frequencies.

Millimetre-wave radiometers detect the thermally induced rotational emission lines of atmospheric constituents. Relevant rotational level populations for these transitions are in thermodynamic equilibrium, and excitation energies are low relative to available thermal energy, and therefore the condition for local thermodynamic equilibrium (LTE) is well fulfilled up into the mesosphere. Heterodyne receivers are used to downconvert the observed atmospheric signal to a lower intermediate frequency while preserving all spectral information. The spectrally resolved line shapes contain altitude information through pressure broadening of the particular emission line. This can be used to retrieve altitude profiles of the volume mixing ratio of the respective atmospheric constituents.

The Institute of Environmental Physics at the University of Bremen has a long history in operating and developing ground-based and airborne mm-wave radiometers. The institute has participated in several intercomparison and validation campaigns of ground-based sensors, and satellite instruments. The data collected by the instruments in Ny-Ålesund are therefore well characterised, and have successfully been used for validating the space-borne sensors GOME onboard ERS-2 and ILAS onboard ADEOS. The instrument at Ny-Ålesund satisfies the very high accuracy standard required by the NDSC data protocol.

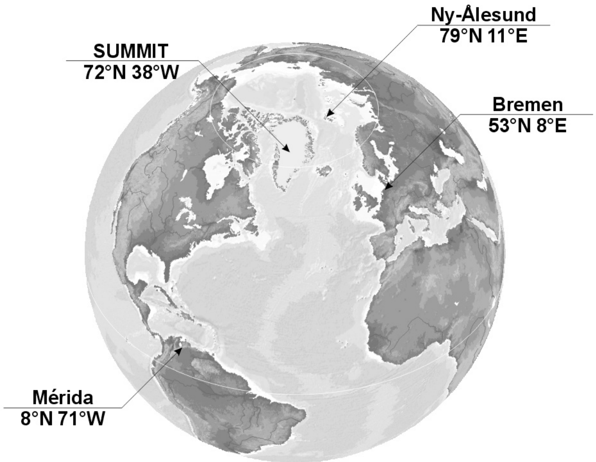

Fig. 1. High-, mid- and tropical latitude observation sites with ground-based mm-wave radiometers, Ny-Ålesund and Bremen are operational stations, Mérida is planned to become operational in February 2002. For Summit development work is presently in progress, operationality is not expected before late 2002 or 2003.

At the Institute of Meteorology and Climate Reasearch at the Forschungszentrum Karlsruhe ground-based mm-wave radiometry has been introduced in 1991 to complement IR observations. Subsequently to a 142 GHz instrument for O_3, which started field operation in 1994, radiometers for ClO and other trace gases at 204 and 278 GHz have been developed [7]. Regular winter campaigns have been performed at IRF/Kiruna since 1996 [8], except for 1997 when an international ClO radiometer intercomparison campaign took place at Ny-Ålesund [9]. In the course of the construction and the operation of radiometers advanced calibration methods and retrieval procedures have been developed.

OBJECTIVES

The trace gases to be measured within this project (see Table 1 and 2) are part of the SCIAMACHY core validation campaign. All data products fulfil the precision criteria specified in the SCIAMACHY Validation Requirements Document. For cross validation purposes this project complements other SCIAMACHY validation projects that observe the same species at the same locations.

Note: ClO is not presently considered a routine SCIAMACHY data product, however ClO retrieval are part of so called scientific projects. Nevertheless since very few ClO validation sources are available world-wide, and because ClO data is provided at two of the sites at no additional costs, this parameter is included in the list of species to be validated. Since the 270 GHz radiometer that will be installed at Mérida is capable to perform HNO_3 soundings, this trace gas will be determined as an additional feature.

Table 1. List of products retrieved by mm-wave radiometry, their altitude range and accuracy

Product	**Altitude range [km]**	**Accuracy**
Ozone profiles	12 – 55	0.2 ppm or 10 %
Water vapour column	-	0.3 mm or 10 %
Water vapour profiles	25 – 55	0.3 ppm or 20 %
N_2O profiles	20 – 55	30 ppb or 15 %
ClO profiles, optional	16 – 35 (17 – 55 at Mérida)	0.4 ppb or 20 %
HNO_3 profiles, optional	17 – 55	1 ppb or 20 %

Besides SCIAMACHY validation the ozone measurements carried out within this project will be used to detect the chemical ozone loss inside the polar vortex, and to study horizontal transport phenomena, as described in [3] and [4]. The water vapour observations will be used as an indicator for the location of Ny-Ålesund with respect to the polar vortex. In Mérida the N_2O data will give information on vertical transport in the stratosphere. Chlorine monoxide measurements allow to determine the importance of anthropogenic ozone destruction and the presence of perturbed chemistry situations, as shown in [5] and [6]. All data will be submitted to the NDSC database.

OBSERVATION SITES

Ny-Ålesund

The high latitude station Ny-Ålesund, Spitsbergen, (79° N, 12° E) is part of the Arctic primary station of NDSC. This station is equipped with mm-wave radiometers to observe ozone, chlorine monoxide and water vapour, all sensors are operational. The data collected by these instruments have been used successfully for validating the space borne sensors GOME onboard ERS-2 and ILAS onboard ADEOS.

Bremen

The instrument of the mid-latitude station Bremen, Germany, (53° N, 8° E) for the detection of stratospheric ozone profiles and total water vapour columns has been tested successfully. It is operational since end of 2000 and presently in the validation phase, which is expected to be finished before the launch of SCIAMACHY.

Mérida

At present two radiometers to observe ozone, nitrous oxide, HNO_3, ClO and water vapour in the stratosphere are being prepared for installation on the top of Pico Espejo near Mérida, Venezuela (8° N, 71° W), at an altitude of 4768 m. Such a high altitude is required in the tropics in order to avoid the high absorption by water vapour in the lower troposphere. The chosen site is well suited because of its excellent infrastructure and the local scientific support provided by the Universidad de los Andes. The Forschungszentrum Karlsruhe will install a radiometer, which operates near 270 GHz and includes an acousto optical spectrometer. The H_2O-radiometer will be provided by the University of Bremen.

VALIDATION INSTRUMENTS

Ny-Ålesund

The Radiometer for Atmospheric Measurements (RAM) consists of three front-ends for the detection of the pressure broadened rotational emission lines of stratospheric water vapour at 22 GHz, ozone at 142 GHz and chlorine monoxide at 204 GHz. The three front-ends use alternately the same back-end, an acousto optical spectrometer, for spectral near real time detection. In winter the ClO measurements have the highest priority followed by ozone and water vapour. In summer only water vapour and ozone are observed. Since the stratospheric emission signal is affected by the tropospheric water vapour absorption, the integration time in order to achieve a sufficient signal to noise ratio depends on observing frequency, emission line strength and tropospheric opacity. In the case of ozone this time varies between

Table 2. List of trace gases to be measured and necessary integration time

Latitude/ Longitude	**Ozone profiles**	**ClO profiles**	**Water vapour profiles**	**Water vapour columns**	**N_2O profiles**	**HNO_3 profiles**
Ny-Ålesund 79° N/ 12° E	0.25 – 1 h	Feb. to April: typ. 10 h	6 – 24 h	0.25 – 1 h	n/a	n/a
Bremen 53° N/ 8° E	typ. 1 h	n/a	n/a	typ. 1 h	n/a	n/a
Mérida 8° N/71° W	0.3 – 1 h	typ. 3 h	6 – 24 h	0.3 h	1 –2 h	1 – 3 h

10 minutes in winter and 1 day for a very humid summer troposphere. The ozone profiles retrieved from the measurements in Spitsbergen have intensively been validated and show good agreement with other sensors at Ny-Ålesund, as shown in [1]. The integration time for a stratospheric water vapour measurement is between 6 h and 1 day in winter. During summer stratospheric water vapour observations are possible under favourable weather conditions. Water vapour columns are derived from the non resonant emission of tropospheric water vapour, producing an offset to stratospheric ozone emission. Chlorine monoxide measurements are performed during the winter month and need typically about 10 hours of integration time during day and night.

Bremen
The BREmen Radiometer for Atmospheric Measurements (BRERAM) operates at a frequency of 110 GHz. This frequency is more suitable to the rather humid tropospheric conditions in Bremen compared to Spitsbergen because tropospheric absorption is lower than at 142 GHz. Integration times will vary between 1 h under favourable weather conditions and 1 day for a humid, warm summer atmosphere. In case of rain, measurements will stop. The BRERAM ozone profiles are presently being validated using data from radiosondes launched at Hohenpeissenberg, Lindenberg, Germany and Uccle, Belgium, and if available profiles derived from GOME data. This process is expected to be finished before the launch of ENVISAT.

Mérida
Two radiometers, MIRA2 and WARAM, sharing a common acousto-optical spectrometer backend will be installed. The radiometer MIRA2 observes emission lines of O_3, ClO, HNO_3 and N_2O in the frequency range 268-280 GHz. This instrument, in operation since 1996, has been developed at the Forschungszentrum Karlsruhe and is well tested and validated during several arctic measurement campaigns. The radiometer WARAM observing the H_2O line at 22 GHz will be provided by the University of Bremen and is based on a similar instrument operating successfully at the NDSC station in Spitsbergen.

The installation of the microwave instruments will start in October 2001; full operation is planned for February 2002. This also is consistent with the present schedule for the validation of the atmospheric research instruments aboard ENVISAT, which is the major goal for the first phase of operation. Beyond this, long-term operation is envisaged to complement the present set of NDSC stations with a tropical location.

VALIDATION METHOD

Profiles of ozone and water vapour (and chlorine monoxide if desired) derived from SCIAMACHY observations and from ground-based mm-wave radiometry will be first processed to get comparable altitude resolution. In a next step the profiles will be compared, considering the very different spatial resolution of both sensors, and also taking into account the particular meteorological conditions. It should be noted that in a recently completed Ph.D. thesis the achievable accuracy for comparing profiles and total amounts of minor constituents, has been carefully analysed for the case of ozone [1] (see also [2]). This analysis included four ground-based instruments (Microwave Radiometer, FTIR, DOAS, and LIDAR), balloon soundings and three space-borne sensors, MLS on UARS, GOME on ERS-2 and TOMS on a NASA Earth Probe. Such an analysis is the basis for any meaningful intercomparison of data obtained from sensors with vastly different observing geometry.

FURTHER RADIOMETER DEVELOPMENT

Beside the above described mm-wave radiometers, part of the SCIAMACHY validation program, it should be mentioned that at present the new mm-wave Radiometer for Atmospheric Measurements at SUMMIT (RAMAS) is being developed for deployment at the SUMMIT research station (72° N, 38° W) in the interior of Greenland at an altitude of 3200 m. The project will be realised by the following partners: University of Bremen, Germany (Co-ordinator), University of Bordeaux, France, University of Leeds, U.K., and the Danish Meteorological Institute. It is supported by the European Commission (fifth frame work programme) and the US National Science Foundation.

Presently available stations in the Arctic are located between sea level and 600 m, where the observing conditions are still severely limited due to high tropospheric attenuation, whereas SUMMIT provides the only high altitude site available in the Arctic necessary for such a sensor. The principle aim will be to measure O_3, ClO, N_2O and HNO_3, over an altitude range and with a vertical resolution as shown in Table 3. These observations will be analysed and compared

Product	Altitude range [km]	Accuracy
Ozone profile	12 – 55	0.2 ppm or 10 %
Water vapour column	-	0.3 mm or 10 %
N_2O profiles	15 – 45	10 to 30 ppb
ClO profiles	15 – 45	0.3 ppb
HNO_3	15 – 45	0.3 ppb

Table 3. List of products planed to be measured with RAMAS and the accuracy of the retrieved products

with a three dimensional model. The observing band for the radiometer will cover the frequency range from 265 to 281 GHz, which is best suited for a site with extremely low water vapour, because it covers a large number of interesting species. It is planned to install RAMAS at SUMMIT in summer 2002. Routine operation can not expected to start before end 2002 or in 2003.

CO-OPERATIONS

Our activities in these projects, in particular for the Ny-Ålesund and Mérida sites, will be conducted in close collaboration with the Alfred-Wegener Institute for Polar- and Marine Research, Potsdam, Germany in addition to the partners already listed above.

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